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Dr. Pratap Narain
Director

PS/Gen/2006
30th May, 2006

Dear Dr. Wani,

Our joint paper on "Strategies for improving soil and water quality in arid and rainfed agro-ecosystems in India" has appeared in the Proceedings of International Conference on Soil and Water Environmental Quality – Issues and Strategies. As requested I am sending you a photo copy of the same.

With best regards,

Yours sincerely,
Narain
(PRATAP NARAIN)

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Strategies for Improving Soil and Water Quality in Arid and Rainfed Agro-ecosystems of India

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Soil quality, though realized synonymous to soil health, is fitness of soil for specific purpose (Carter *et al.* 1997) adjudged by the factors chosen for soil classification, soil suitability and land capability (Carter *et al.* 2004). It examines spatial and temporal variations induced by land use policy or management, based on soil physical, chemical and biological indicators. Soil organic carbon (SOC) is most reliable, versatile and easily assessable indicator, encompassing interactive effect of several indices. Plateuing or decreasing crop yield at current level of managements indicates declining soil and water quality in arid and rainfed ecosystem of India, which cover more than 65% (92 M ha) of cultivable land, spread over in 18 states and 12 agro-ecological regions. Wind and water erosion, drought and desertification, salinity and sodicity, paradigm shift in land use, nutrient depletion and adoption of intensive cultivation practices aimed at maximizing crop productivity are causes of soil and water quality decline. Erratic rainfall and exploitation of land, water and vegetation resources by ever increasing human and livestock population further intensifies the problems of deteriorating soil quality. Increasing salinity, residual carbonate, alkalinity and contamination of surface and ground water through heavy metals, nitrates, fluoride and arsenic are the reflections of declining soil quality. Recycling of contaminated water through irrigation is further cause of concern. These are emerging issues which call for comprehensive strategies of land management including erosion control, alternate land use plan, residue management, minimum tillage, intercropping, nutrient and water management through organic, inorganic and biofertilizers and diversification of agriculture for enhancing soil quality in a system approach. Present paper analyses these issues, highlighting the factors responsible for declining/enhancing soil and water quality in arid and rainfed ecosystems and also focuses on a holistic approach, involving suitable and alternate land use options, appropriate technology and their execution on watershed basis for maintaining soil and water quality.

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Geographical Distribution

Arid and rainfed agro-ecosystems, constituting more than 65% of the net cultivated area, have an important place in Indian agriculture. Arid region alone covers in 38.7 Mha, of which 31.7 Mha is hot arid western Rajasthan, northwestern Gujarat and southwestern part of Haryana and Punjab, while cold arid region on mountainous slopes and narrow valleys in J&K and H.P. occupies 7.0 Mha lands. Semi-arid, sub-humid rainfed ecosystems along with arid region cover about 92 Mha, which is distributed in large parts of India (Table 1) having about 65% unirrigated area, varying from < 7% in Punjab to > 87% in Maharashtra.

Agro-Climate

Rainfall in hot arid ecosystem varies from <100 to 490 mm with 60 to 90 days length of growing period (LGP) supporting pearl millet and arid legumes based cropping system. Semi-arid and sub-humid part of rainfed ecosystem receive rainfall from 490 to 750 and 750 to 1200 mm, respectively with LGP of 90 to 120 days in former and 120 to 150 in latter. Sorghum, groundnut and pulse based production systems prevail in semi-arid, while sub-humid region is dominantly under rice production system.

Soil Resources

Soils of these ecosystems belong to Alfisols, Aridisols, Inceptisols, Entisols and Vertisols (Table 2), distributed in ten soil order associations. Major soil constraints are low soil organic carbon and fertility, P deficiency, physical degradation and accelerated erosion. Besides these, human induced soil degradation such as deforestation, overgrazing, terrain deformation and loss of topsoils, salinity and sodicity, water-logging, gradual building of inorganic

Table 1. State wise rainfed areas in India (lakh hectare)

State	Net sown	Net irrigated	Rainfed (%)
A.P.	110.41	66.90	60.60
Assam	27.06	21.30	80.90
Bihar	77.15	43.65	56.60
Gujarat	92.91	69.21	74.50
Haryana	35.08	7.50	21.40
H.P.	5.74	4.70	82.00
J&K	7.34	4.20	57.20
Karnataka	107.09	84.00	78.40
Kerala	22.48	19.20	85.40
M.P.	193.63	147.40	76.10
Maharastra	177.30	155.60	87.80
Orissa	63.37	44.00	69.40
Punjab	42.15	2.80	6.60
Rajasthan	154.89	115.50	72.40
Tamil Nadu	57.26	31.20	54.60
U.P.	172.99	67.60	39.10
West Bengal	53.34	34.20	64.10
Others	13.89	11.20	80.50
Total	1414.08	926.10	65.50

However, large variations are noticed in ground water quality. About 32 to 84% of well waters in India are poor. High salinity is reported in ground waters of arid agro ecosystem while alkali water predominates in semi-arid parts of India, receiving 500 to 700 mm rainfall. High RSC water with low salinity is common in central and southern part of rainfed agro ecosystem (Gupta *et al.* 1994). Ground water is contaminated with toxic level of B, F, NO_3^-, Se and As in some parts of the region.

Declining water table as a consequence of high withdrawal of water for intensive cultivation is becoming important issue in arid and rainfed agro ecosystems. An alarming rate of declining ground water, more than 4 meters during 20 years (1981-2000) in some parts of ecosystems depicts gravity of situation. Consequently, a sizeable area turns to gray zone in due course. About 60% blocks of Rajasthan has been reported in gray zone. Water quality deterioration is attributed partly to increased salt concentration and partly to intermixing of water from limestone aquifers.

Table 2. Soil resources of arid and rainfed agro ecosystems

Soil orders	Constraints for the dominant soil order
	Arid Agro-ecosystems
Entisols-Aridisols	Very low temperature, shorter growing period, shallow and gravelly soils, and high calcareousness.
Entisols- Aridisols	Wind erosion, drought, moisture stress, crusting and secondary salinization
	Rainfed Agro-ecosystem
Aridisols-Inceptisols	Drought, moisture stress, poor drainage, high runoff and secondary salinization
Inceptisols-Vertisols	Erosion, nutrient imbalance, secondary salinization and alkaline ground water
Inceptisols- Entisols	Nutrient depletion
Vertisols- Inceptisols	Massive structure, poor tilth, drought stress and water erosion.
Inceptisols- Vertisols	Water erosion, low organic matter and nutrient imbalance.
Alfisols-Vertisols	Weak soil structure, crusting, compaction, low AWC and nutrient depletion and water erosion
Vertisols-Alfisols	Massive structure, poor tilth, drought stress, waterlogging during early stage and droughtiness at latter, nutrient depletion and water erosion.
Inceptisols-Alfisols	Erosion, severe gully erosion in latterites, subsoil gravelliness, P fixation low organic matter content, nutrient imbalance, low PAWC and acidity at places.

carbon and hard setting behavior dominantly occurs in the ecosystems.

Water Resources and Quality

Primary source of water is precipitation, recycled through canal network from different river systems. Quality of river water in canal network is by and large very good with a few exceptions. The Ca+Mg is predominant cations in Ganga, Gomati, Ghaghra and Gandak flowing through upper reaches, while bicarbonates in excess of Ca+Mg is observed in low land waters of Chambal, Ken, and Betwa rivers. The Mg/Ca ratio is reported to increase during lean period to latter (Sarin *et al.* 1989) due to preferential precipitation of calcium.

Soil Quality

Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity; maintain or enhance water and air quality, and support human health. It is to be considered in the realm of sustainability level and socioeconomics influencing the level of productivity. In the context of 21st century, soil quality must meet the need of four basic functions in the interest of mankind.

- Maximize long-term productivity per unit input of non-renewable resources.

- Minimum risks of environmental pollution, especially with regard to air and water quality.
- Moderate fluctuations in components of the water and energy budget due to change in land use and land cover.
- Proxy for interpretation of past global changes.

Need of land base production, is widely recognized, yet the importance of soil in mitigating the rate of enrichment of atmospheric CO_2 and improving water quality is yet to find due place. The drastic increase of CO_2 in atmosphere is attributed to fossil fuel combustion and land use change. Latter includes deforestation, biomass burning, conversion from natural to managed ecosystems and intensive cultivation (IPCC 2001). The SOC depletion leads to decline in soil quality and agronomic productivity. Adverse impact of declining soil quality on productivity is strikingly apparent in arid and rainfed agro-ecosystem, where productivity is stable or declining at the current level of management. The resource poor farmers cannot afford the inputs needed to restore soil quality and enhance/ replace the depleted SOC pool. Indeed, the soil quality and constraints of the region are to be identified and land use and technology should be accordingly promulgated.

Soil Quality Indicators

The soil quality indicators (Table 3) *viz*., physical, chemical and microbiological (Doran *et al*. 1996) and their interactions (Lal 2004) and relevance (Fig.1) to ecosystem show that soil organic carbon (SOC) is the most versatile and easily assessable index of soil quality.

SOC Stock in Arid and Rainfed Ecosystem

Hot arid, semi-arid and sub-humid parts of the ecosystems fall in SOC deficient zone (<1%) in the surface soils (Velayutham *et al*. 2000). Representative carbon stock (RCS) was 35.0 to 39.2 and 62.6 to 68.9 kg m^{-2} in 0-30 and 0-150 cm soils, respectively in cold arid region (Table 4), covering parts of northern India, where low temperature round the year favors organic carbon accumulations. Sparse vegetation, high temperatures and low rainfall impart lower organic carbon stocking in hot arid region. Semi-arid regions in rainfed agro-ecosystem show low to medium SOC stock, ranging from 1.2 to 3.5 and 4.4 to 10.4 kg m^{-2} in 0-30 and 0-150 cm, respectively. Sub-humid regions although bless with high rainfall and thicker vegetative cover contained 1.0 to 2.8 and 3.5 to 7.0 kg m^{-2} SOC, which are comparatively lower than semi-arid and some times resembles to hot arid region. In general, SOC seems to decrease from sub-humid to arid region. However, present observations defy the universal relationship between climate and SOC (Schlesinger 1982), which believes that higher

Table 3. Key soil quality indicators

Soil quality indicators	Relationship to soil condition and function	Ecological relevant values/ unit (Comparison for evaluation)
A. Physical		
Texture	Retention and transport of water and chemicals.	Per cent Sand, silt and clay content; less eroded sites or landscape position
Depth	Estimate of productivity potential and erosion	Cm or m; no cultivated sites or varying landscape positions
Infiltration and bulk density	Potentiality of leaching, productivity and erosivity	Mm/2.5 cm of water and g/ cm^3; row and/ or landscape position
Water holding capacity	Related to water retention and transport	Per cent (g cm^{-3}), cm of available water/ 30 cm; precipitation intensity.
B. Chemical		
Soil organic carbon	Define soil fertility, stability and erosion extent	kg C or N/ha/30 cm; non cultivated or native control
pH	Define biological and chemical activity threshold	Compared with upper and lower limits for plant and microbial activity
Electrical conductivity	Define plant and microbial activity threshold	dS m^{-1}; compared with upper and lower limits for plant and microbial activity
Extractable N, P, K	Plant available nutrients and potential to N loss	kg/ha/30 cm, seasonal sufficiency for crop growth
C. Microbial biomass		
Microbial biomass C&N	Microbial catalytic potential and repository for C and N modeling	kg N or C/ha/30cm; relative to total C &N or CO_2 produced
Potentially mineralizable N	Soil productivity and N supplying potential	kg N or C/ha/30cm; relative to total C &N or CO_2 contents
Soil respiration, water content and temperature	Microbial activity measure	kg C/ha/day; relative microbial biomass activity; C loss Vs inputs and total C pool

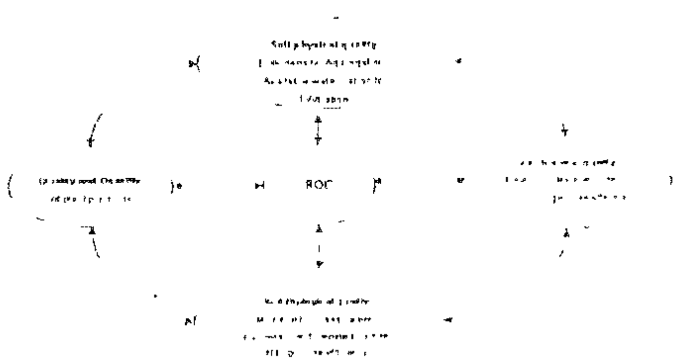

Fig 1. Interactive effect of SOC and other soil quality indicators

Table 4. Representative SOC stock (kg m⁻²)

Climate	Soil depth	
	0-30 cm	0-150 cm
Cold arid	35.0-39 2	62 6-68 9
Hot arid	0 8-1.2	3 3-8 5
Semi arid	1.2-3 5	4 0-10 4
Sub humid	1 0-2.8	3 5-7 0

rainfall and cooler environment favors organic carbon stocking Predicted and observed values (Fig. 2) based on the relationship (Y= 0 0019 rainfall, R^2=0.50) further endorse the contention that rainfall influences only 50% of SOC stock, while management govern remaining 50% of SOC in arid and rainfed agro-ecosystems.

Carbon Stock in Arid and Semi-Arid Regions of Rajasthan

The SOC stock is higher in Alfisols both at the surface and in the profile Vertisols, Inceptisols, Aridisols and Entisols come next in order of descending SOC after Alfisols Thicker vegetation, traditional agro-forestry system and better aggregation as a result of higher free iron oxide to clay ratio (Shyampura *et al.* 1994) protect SOC from decomposition. However, smectite and vermiculite (Singh *et al.* 2002) having higher surface area could not preserve higher

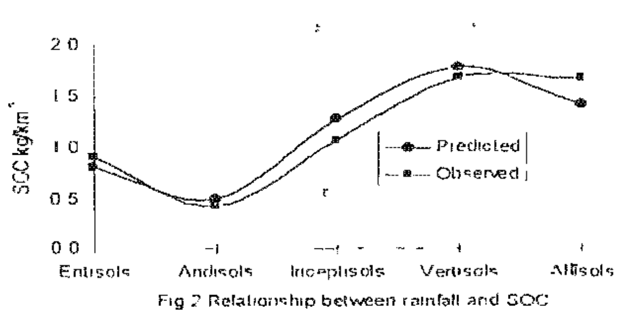

Fig. 2. Relationship between rainfall and SOC

SOC in Vertisols, because these are intensively cropped with annual and perennial crops. Low and scanty rainfall, high temperature and lower clay content dominated with mica interstratified mineral account for lower organic carbon stock in Entisols and Aridisols (Fig 3). Inceptisols are intermediate with respect to SOC stock between Vertisols and Aridisols.

Carbon stock (CS) including organic and inorganic forms of carbon was 2.09 Pg (1Pg= 10^{15} g) in soils of Rajasthan. Surface horizon held around 653 Tg (1 Tg=10^{12} g) accounting for 31% of CS Torriorthents and Ustorthents together and Torripsamments belonging to Entisols housed 2.92 and 28.73% of CS, respectively. Ustifluvents, Ustipsamments and Torrifluvents another great groups of Entisols accounted for 2,61% of carbon stock. Haplocambids in Aridisols hold 400.9 Tg carbon contributing 19.2% in CS, while Petrocalcids, Haplocalcids and Haplogypsids another great groups of Aridisols together were responsible for 281.5 Tg carbon in the state. Latter together housed 13.5% of CS in Rajasthan Haplargids and Haplustalf belonging to Aridisols and Alfisols, respectively had only 1 4% of CS Haplustepts and Haplusterts of Inceptisols and Vertisols accounted for 610 8 and 105.9 Tg carbon, holding 23.9 and 5.1%, respectively of CS. Representative carbon stock was 23 45, 16 25 and 11 08 kg m⁻² in Petrocalcids Haplogypsids and Haplocalcids, whereas Haploargids and Haplosalids were maintained 6 to 9 kg m⁻² in soil profile. Torrifluvents was higher (13 kg m⁻²) among the great group of Entisols. Haplusterts and Haplustepts showed carbon stock in the range of 7 to 10 kg m⁻². Latters were much lower to similar soils of Dakota U.S.A, varying from 19.4 to 20 7 kg m⁻² (Franzmeir *et al* 1985). Carbon stock was between 2 to 2.5 kg m⁻² in the first 25 cm of the soil profile of Haplusterts, Ustorthents and Haplogypsids. Remaining great groups showed carbon stock below 2 kg m⁻² at the surface.

The forest ecosystem designated as scrub land in semi-arid parts of Rajasthan contained 170 kg/km² SOC (Fig. 4) However, aridity and severe wind erosion pull down SOC to the level of 5 0 kg km⁻² under similar situation in arid part of Rajasthan. Organic carbon stock was almost similar under mono- (47 kg m⁻²) and double-cropping (44.6 kg km⁻²) systems in latter, which is a rare phenomenon. Intensification of agriculture brings down SOC from 64 to 10 kg km⁻² in the semi-arid part of Rajasthan

Declining Organic Carbon in Arid Rajasthan

Organic carbon stock declined regularly from 1975 to 2002 except in Bhagasani series of Jodhpur

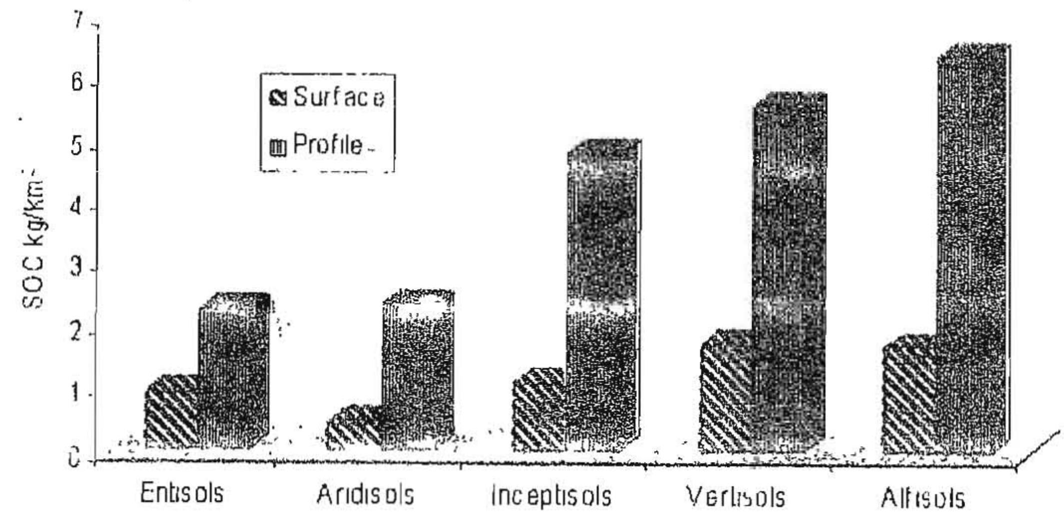

Fig. 3. SOC in different soil orders of arid and semi arid region of Rajasthan

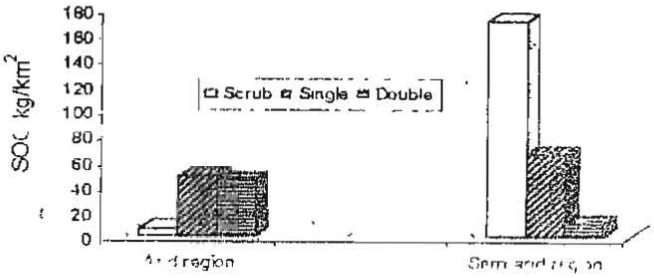

Fig. 4. SOC distribution with respect to land use

Table 5. Organic carbon stock (kg m^{-2}) in soil series of Jodhpur

Soil series	Years of observations			
	1975	1992	1997	2002
Coarse loamy soil family				
Malkosani	3.30	3.15	3.08	3.00
Bhagasani	3.70	3.80	3 85	3.90
Pal (d3)	2.00	1.90	1.85	1.80
Pal (d2)	2.90	2 75	2.68	2.60
Pipar	3.20	3.20	3.20	3.20
Kolu	1.50	1.48	1 46	1 45
Bap	1.40	1.30	1.25	1.20
Fine loamy soil family				
Bhopalgarh (d2)	1.60	1.52	1 51	1.50
Gajsinghpur	3.90	3.55	3.52	3.50
Bap variant	3 20	2 94	2.92	2.90
Bhopalgarh (d3)	2 90	2.64	2.62	2.60
Asop	4.40	4 05	4.02	4.00
Sandy soil family				
Chirai (n)	1 40	1.27	1.20	1 10
Chirai (sh)	1 40	1.28	1.23	1.14
Chirai (h)	0 70	0.63	0.60	0.55
Shergarh	1.40	1.29	1.23	1.15
Dune	0.70	0.65	0 62	0.58

n. normal; sh. slightly hummocky, h· hummocky

district (Table 5). The average value elucidates that loss of SOC occurs at the rate of 6.0 g m^{-2} $year^{-1}$ in coarse loamy and 3.6 g m^{-2} $year^{-1}$ in fine loamy soils. Rate of loss was as high as 14 g m^{-2} $year^{-1}$ in sandy soils. Declining SOC is a matter of concern, as it may turn critical for economic production in the years to come.

Factors for SOC Decline

Drought and Desertification

Drought in arid region usually occurs once in 2.5 years, while intensity and frequency of drought is milder in rainfed ecosystem. Drought not only reduces recycling of organic residues in soils but also accelerates wind erosion. An analysis of rainfall data from 1992 to 2002 in Jodhpur district of Rajasthan (Fig.5) indicated a continuous decline of mean annual rainfall from 450 to 100 mm, which may be one of the reasons for decreasing SOC by 10.4% from 1975 to 2002.

Soil Erosion

Soil erosion, mostly active on carbon rich surface soils, leads to SOC and nutrients loss. Water and wind erosion affect about 150 and 10.8 M ha in India (Sehgal and Abrol 1994), of which 140 Mha is under severe and very severe category. Loss of biological productivity is reported 25 to 50 and >50% in severely and very severely water eroded Inceptisols and Vertisols, respectively (NBSS&LUP 1990). The SOC depletion was about 50% from wind eroded cultivated soils and culturalable wasteland as compared to their non-eroded counterpart, while SOC loss was only 30% in permanent pasture (Narain 2001). Our calculation indicates that SOC declined by 10.4% in different soil series affected with wind and water erosion in Jodhpur district of Rajasthan in a span of 27 years.

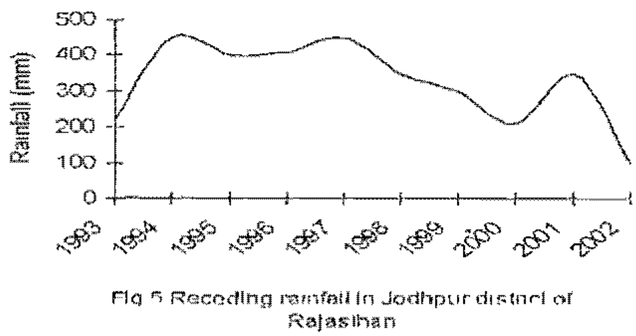

Fig. 5. Receding rainfall in Jodhpur district of Rajasthan

Cropping with Unbalanced Fertilization

Depletion of nutrients from the agriculture field is severe threat to SOC. Application of nutrient lower than recommended dose decreased fertility level, which resulted in sparse plant cover and lower vegetative inputs to soils. In semi-arid areas removal by crop was far more than added through fertilizers (Katyal 2003). Alfisols, Ultisols and Oxisols with low cation exchange capacity were the heaviest looser (Katyal 2003). The SOC loss ranged from 0 22 to 6.0% over initial value in different cropping sequences of India because of unbalanced fertilization, whereas depletion of SOC was far less 0.22 to 2 92% under balanced fertilization (CRIDA 2003-04) Improper balance of fertilizer induces depletion of phosphorus and potassium by 7 7 and 13 4%, respectively in arid soils of Jodhpur from 1975 to 2002 (Singh and Narain 2005). This may also be one of the contributing factors for depletion of SOC by 10.4% during the estimated period.

Shift in Land Use

Traditional farming system was an extensive practice with low yields, which was in sustainable harmony with the carrying capacity set by the nature. Low productivity system has lost relevance in view of increasing demand of food, fiber and wood Since 1951- 52 there has been an increase of 36, 22 and 54 M ha irrigated, net sown and double cropped area, respectively on the cost of fallow, pastures and grazing lands and tree grooves. Intensive farming needs high productivity, which satisfies needs of stakeholders in an economically favorable way and simultaneously contains curative action for preserving quality and preventing soil degradation These appear non-sustainable in absence of holistic land management The former was perused and latter was ignored. These altogether trigger soil quality depletion through initiation of wind and water erosion in shape of terrain deformation, loss of topsoil and nutrients and increased overburden sand. Perpetual explosive view of this kind is a serious threat to soil quality deterioration, which continues to spread at the rate of 6 mha per annum (FAO/UNEP 1984)

Salinity and Sodicity

Salinity and sodicity in soils, lead to the decomposition of SOC (Eswaran *et al* 1999), which cover 10.1 M ha apart from 2.2 M ha saline flats. Soils affected with medium and high level of salinity occur in 2.0 and 5.3 M ha land (Sehgal and Abrol 1994) Loss of biological productivity ranged from 10 to 25% in Inceptisols and Alfisols affected with medium to high sodicity, while decrease of productivity has gone >50% in Vertisols affected with same level of sodicity (NBSS&LUP 1990)

Summer Fallowing

According to Doran and Zeiss (2000) summer fallowing causes SOC loss 320 to 350 kg in semi-arid tropics, About three to four months after *rabi* harvest and before *kharif* sowing fallowing of land is common in India Pearl millet- fallow- pearl millet rotation commonly practiced in arid region might be one of the reasons for SOC loss.

Effluents Deteriorate Soil Quality

Urbanization and industrialization cause detrimental effect on soil and water quality. Improper management of huge quantity of city garbage, sewage sludge, sewage water, industrial effluents discharge in to the water stream and agricultural chemicals contaminate the soils and water, leading to heavy metals builds up Accumulations of metals are higher at the surface particularly in clayey soils than the subsurface (Rattan *et al.* 2002). Soils along the drier riverbed often are potential accumulator of Cd, Pb and As. Discharge from textile industry in arid Rajasthan increased ECe, SAR and ESP of treated soils from 2.5 to 193.6 dS m^{-1}, 24 to 485 and 25 to 87, respectively. Chloride and sulphate increased from 14.5 to 28.30 and 3.0 to 107 me L^{-1}, respectively. Effluents of textile industry also deteriorate the quality of water by increasing total dissolve salts (TDS), SAR and chlorides by 50, 10 and 40 times in the same sequence Deterioration in water quality is more serious near the discharge and influence of effluents declines with increasing distance from the source (CAZRI 1997).

Agro Techniques Enhancing Soil Quality

Erosion Control

Soil erosion continues to be a serious threat for maintaining soil quality Adequate wind and water conservation measures through mechanical/ vegetative means are basic to land management. These are windbreaks, shelterbelts and sand dune fixation in arid agro-ecosystem, contour cultivation, contour bunding bench terracing and land cover management in rainfed agro ecosystem. An increase of SOC from 850 to 1400 kg ha^{-1} during 1994 to 1999 was observed beneath the shelterbelts used for controlling wind erosion (Solanki *et al.* 1999). Increase in the level of nitrogen, phosphorus and potassium has also reported in the area protected from shelterbelt. Contour bench terracing reduced soil loss from 10 to 1.2 t ha^{-1} and runoff from 36 to 7.4% in semi-arid region. Similarly reclamations of deep gully through vegetative reduced soil loss from 3.0 to 1.26 t ha^{-1} and runoff from 14.7 to 5.8% in ravenous region (Samra & Narain 1998). Thus, protecting soils at the place of formation through conservative measures reduces the risk of soil quality deterioration.

Alternate Land Use System

Forestry, horticulture, agri-horticulture, silvi-postoral, agri-silvi-postoral and intercropping instead of annual crops improve soil quality. A higher SOC (32 Mg ha^{-1}) has been noticed under forestry than 31, 30 and 28 Mg ha^{-1} in horticulture, cotton+legume and cotton based system, respectively in Vertisols of M.P (IISS 2002-03). Agri-horticulture system increased SOC from 600 to 1600 kg ha^{-1} during 1989 to 95 at Jhansi (U.P). It also simultaneously raised the level of available nitrogen, phosphorus and potassium. Sivi-postoral and Agri-silvi-postoral system increased SOC by 400 and 150% over the control in a span of 5 years, while nitrogen, phosphorus and potassium increased by 175, 125 and 165% (Solanki *et al.* 1999).

Afforestation

Prosopis juliflora and *T. arjuna* afforesation on a highly degraded land brought down pH to 8.03 and 8.15, respectively from 10.3 with simultaneous increase of SOC by 0.46 and 0.35% over the initial level of 0.12% (Singh and Singh 1993). However, afforesation with *E. tereticornis* and *A. nilotica* on the similar kind of degraded land reduced pH up to 9.18 and 9.03 with corresponding increase of SOC by 0.21 and 0.32%, respectively (Singh and Singh 1993).

Legume Based Crop Rotation

Pearl-millet- moth bean rotation of four years in arid Rajasthan maintains initial SOC of 0.22 and 0.14% in surface and subsurface, while a rotation involving three years of moth bean or cluster bean with a year of pearl millet increased SOC. A rotation of fallow with two years of legume and a year of pearl millet also increased SOC (Kumar *et al.* 1997). Thus incorporation of legume in the cropping calendar is beneficial for the maintenance of soil quality.

Pasture Improves Soil Quality

Intercropping of *C. cilliaris* and *Clitoria ternatia* added SOC by 0.33 and 0.44 kg km^{-2} at the surface and in 100 cm soil profile of arid Rajasthan during three years of experimentation, while an increase of 0.2 and 0.45 kg km^{-2} could be executed with intercropping of *C. cilliaris* and *Lablab purpures* in the same sequence. Pasture with *C. cilliaris* alone added SOC in the soil over the initial stock by 0.2 and 0.35 kg km^{-2}. Therefore pasture improvement with intercropping of *C. cilliaris* and *Clitoria ternatia* or *Lablab purpures* is beneficial for raising SOC in arid region.

Reclamation of Saline and Sodic Soils

Combined application of 20 t ha^{-1} of FYM with gypsum @ 25 and 50% requirement decreased ESP from 89 to 59 and 51, respectively in 1990 at Karnal in Haryana, while in the second year ESP had gone down to 55 and 50 in the same sequence. Treatment was more effective in soils of lower clay content (Yadav 2003). Drainage is necessary for amelioration of saline soils. Sub-surface tile drainage placed at 1.75 m depth and 25, 50 and 75 m spacing started in 1984 on a highly saline sandy loam soils (ECe 25 to 80 dS m^{-1} in 0-15 cm), having high salty ground water (EC 10-40 ds m^{-1}) at Sampla in Haryana, resulted in significant salt removal and increased crop yields (Yadav 2003). However, disposal of salt and other contaminants requires special attention after placement of tiles. Use of salt-tolerant crops, low-volume irrigation, and various management techniques are other options for minimizing the effects of salts. Alternatively biodrainage may also be used.

Tillage and Residue Management

Minimum tillage in combination with both green manure and recommended dose of fertilizer is beneficial for improving soils quality. Broad bed furrow (BBF) with 100% recommended dose of fertilizers (RDF), green manure and application of other deficient nutrient increased SOC by 0.8% in Vertisols of M.P. However, BBF with 100% RDF and green manure could raise SOC only by 0.6% over the initial level of 0.5% under conventional tillage. The BBF with 100% RDF could not enhance the level of SOC from the initial level (IISS 2003-04). The BBF and green manure combination not only increased SOC but also improved soil moisture, porosity, mean weight diameter, infiltration rate and nutrient uptake. The result was similar in arid region, where SOC and hydrolysable nitrogen increased after practicing no tillage (Singh *et al.* 1998).

Residue management and minimum tillage are also important for raising SOC in soils. Residue production in India is nearly 340 million tonnes (Lal and Kimble 2000). About 107 million tonnes residue of wheat, beans, chickpea and soybean used for cattle feeding, while remaining 233 million tonnes are burnt or used for other wasteful purposes. This could be returned to the soils with proper management for enhancing SOC level. However, plant nutrients requirements for targeted yield cannot be met from utilization of available organic resources. Therefore, an alternative feasible option is to be used with all available organic resources, supplemented with chemical fertilizers. Once SOC is enhanced dependency on inorganic resources can be minimized. A higher pearl millet yield and increased SOC by incorporating cluster bean and moong bean residue along with nitrogenous fertilizers was recorded in arid Rajasthan (Aggrawal *et al.* 1997).

Integrated Use of Organic and Inorganic Fertilizers with Suitable Land Use

Combined application of organic and inorganic fertilizers has been found beneficial for enhancing the soil quality at different locations. An increase of SOC by 1.10, 0.88, 5.54, 0.16 and 0.16 over the initial stock of 15.62, 9.9, 10.0, 12.0, 16.2, and 14.8 Mg ha^{-1}, respectively has been observed under rice-wheat, soybean-wheat, sorghum-wheat, finger millet-wheat and rice-wheat system in 5 to 30 years of duration (CRIDA 2003-04). However, sorghum- wheat cropping sequence sequestered highest SOC than any of the system on supplying adequate dose of fertilizers through manures and fertilizers, indicating the suitability of the sequence with respect to Vertisols in Maharastra. Integrated nutrient management also raised SOC by 0.2 and 0.6% in sandy and black soils at Jabalpur (Nambiar 1995), while an application of 40 kg of nitrogen through urea and 5 tonnes of FYM increased SOC in arid agro ecosystem of Rajasthan (Kumar *et al.* 2004).

Effective Water Harvesting and Irrigation Techniques

Rain water conservation, land treatment through mechanical and vegetative barrier and adoption of suitable farming techniques increased water availability, ground water recharge and cropping intensity in different watersheds. A better land cover, on supply of adequate moisture protected SOC from sun and rain beating. Ultimately these techniques help in maintaining and building of soil and water quality. Runoff from high intensity storm could be harvested in dug out ponds, improved *tanka* and *nadi* and preserved for protective irrigation of *kharif* or *rabi* crops, which could maintain vegetative cover round the year. *Khadin* cultivation is another way of water harvesting, common in Jaisalmer district of Rajasthan, where the water from upper reaches is collected against embasement at depressional part of the landscape. The collected water is generally used for drinking purposes and the good harvest is obtained in *rabi* or *kharif* with residual moisture. About 10.2% moisture is recorded in 60 cm of the soil profile in the lower reaches after 7 days of sowing, whereas the moisture was only 3.3 to 6.0% in upper and middle reaches (CAZRI 2002). Sufficient moisture availability remained in the soils round the growing season in lower reaches. A bumper harvest in *kharif* could be possible in *khadins* during the worst drought of 2002 (56 mm seasonal rainfall), when entire crop is failed in the region. Use of sprinklers and drips on undulating topography of arid region further enhance the efficacy of harvested water for increasing vegetative input to the soils.

Diversification of Agriculture

Diversified farms involve growing of variety of crops in a rotation with support of animal. These are usually more economically and ecologically resilient. The deterioration in soil quality not only occurs as a result of growing of annual crops, requiring specific and high management but also keeping land out of agriculture causes serious problem. Diversification integrating both crops and livestock in the farming system not only buffers a farm against the depletion of soil quality, but also reduces economic risk of farmers. Pasture and forage crops in rotation enhance soil quality and reduce erosion; livestock manure, in turn contributes to soil fertility. Livestock can buffer the negative impacts of low rainfall periods by consuming crop residue and provide alternatives to the community. This can help cushion farmers against trade and price fluctuations in conjunction with cropping.

Correcting Water Quality

Most of the world's fresh water falls as precipitation and interact on lands managed for agriculture. Marked changes in landscapes for crop production have drastically altered hydrology of ecosystems. Soil erosion causes severe deterioration of surface and groundwater quality. Over application of fertilizers and pesticides contaminates surface and ground water by pesticides residue, nitrates and phosphates. The problem of nitrate contamination is reported from some part of rainfed ecosystem, while that of fluoride and selenium are overwhelming in arid part of Rajasthan. Low organic carbon often affects soil quality by decreasing the water stability of aggregates, microbial activity, earthworm population and water retentions. The net result is unfavorable soil physical conditions to filter the contaminants

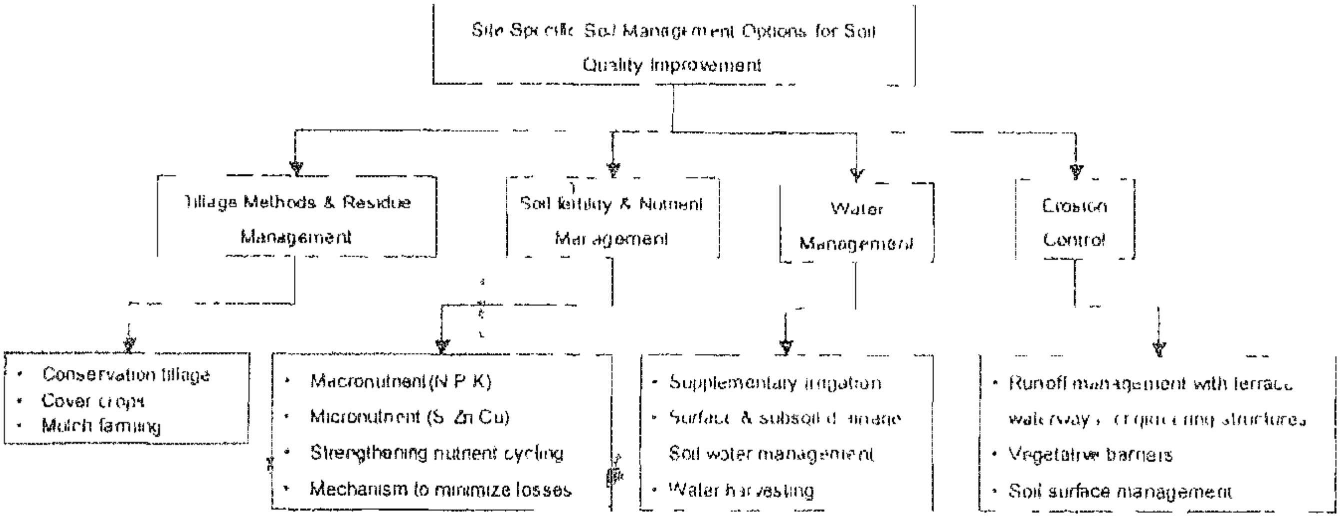

Fig 6 Strategies for improving soil and water quality

and protect the water quality Increasing reliance on agricultural chemicals and irrigation and intensification of agriculture has further aggravated these problems Good quality water is found beneath the well maintained landscape and soils Therefore, emphasis should be on the maintenance of soil quality through management of nutrients, pesticides, animal and other residues wisely, and maintain plant cover on the soil during periods of intense rainfall

Strategies for Improving Soils Quality

Holistic sustainable land management to optimize multifarious functions, while maintain or promote soil quality calls for site-specific management out lined in figure 6 (Doran and Parkin 1996, Lal 1995) The strategy encompasses integrative approach for control of soil erosion, conservation tillage, including residue management, crop rotation with inclusion of legumes, various facets of soil and water management, alternate land use system and diversification of agriculture The specific recommendation for the improvement of soil and water quality in arid and rainfed agro ecosystem is elucidated in table 6 The execution of such programme should be taken on watershed basis The improved management practices in a watershed on Vertisols at ICRISAT increased SOC at the surface and in the soil profile of 120 cm, which may attain new equilibrium in near future (Wani *et al* 2004) Biological productivity has been increased from 26 to 77 kg ha^{-1} yr^{-1}

Table 6 Strategies for improving soil and water quality

A Arid ecosystem
Technology – Shelterbelt & wind break, dune stabilization for controlling wind erosion silvi pasture runoff harvesting and soil moisture conservation, minimum or no tillage, and avoid summer fallowing drought resistant crops, conservation irrigation sprinkler and drips and mulching
Non-arable – Silvipasture agri-silvipasture agri-horticulture & agri-hortipostoral
Arable – Short duration legumes (moth, moong, cluster beans and cowpea) mixed cropping
(Pearl millet cluster bean + sesame), pearl millet cluster bean, ley farming (agri pasture) and strip cropping
B Semi arid ecosystem
Technology – Tillage and residue management, soil and water conservation techniques and integrated nutrient management
Non-arable land – Agri-horticulture and agri-hortipostoral system
Arable land – Rice+sesbania, castor+ tuber crops maize+ legumes
Crop rotations – Rice/maize/finger millet/ ground nut- horse gram/ chickpea rice-chick pea, rice linseed and finger millet-chick pea
C Sub-humid ecosystem
Technology – Soil and water conservation water harvesting efficient irrigation reclamation of saline & sodic soils
Non arable land – Silvipasture, horti-postoral system, agri hortipostoral
Arable land – Intercropping sorghum+legume cotton+legume maize + legume sunflower+ legume, groundnut+legume
Crop rotations – Legume-mustard legume-barley, rice chickpea soybean-wheat, maize+legume wheat/ mustard, rice-wheat-legume-wheat

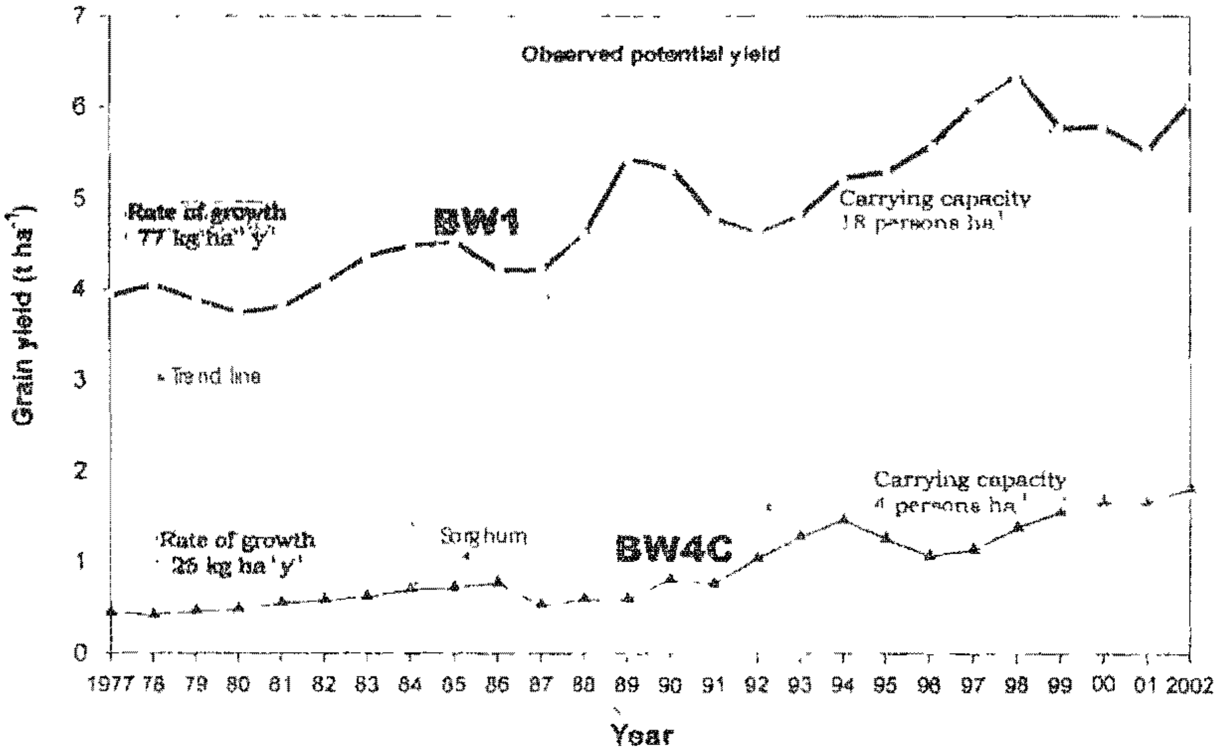

Fig. 7.

(Fig. 7), with increase in carrying capacity from 4 to 18 persons / hectare.

Soil Quality Monitoring

Finally monitoring of soil quality should be undertaken for assessing the impact of land use and management practices, using different mathematical models. A simple regression model (SOC = 4.4 + 0.0001052 (rainfall, mm) + 0.43914 (canopy cover) - 0.00505 (clay) + 0.008722 (Silt) - 4.53 (Tillage), $R^2 = 0.98$) based on annual rainfall, silt and clay content and with due weightage to tillage and crop canopy cover explained around 98% variations in SOC. The model has been validated for the soil series of Jodhpur district mapped during the year of 1975. Model predicted 4.2 to 4.5 kg m^{-2} maximum SOC could be stocked in soil series control section of Jodhpur soils. The major share of which comes from vegetative cover. The SOC for the year of 1992 has also been predicted and validated (Fig. 8).

Summary and Conclusions

Organic carbon has been considered as the most crucial factor for maintaining soil quality. The factors affecting carbon stock and cause of soil quality decline in arid and rainfed agro-ecosystem have been systematically analyzed. Technological options for enhancing soil and water quality have been presented. Suitable and alternate land use system depending up on the soil type and length of growing period, conservation tillage, frequent incorporation of cover crops in rotation cycle have the potentiality of enhancing soil quality.

Application of FYM, bio-fertilizers along with proper dose of macro- and micro-nutrients are essentially required. Incorporation of legumes in cropping calendar is essentially stressed to reduce the dose of nitrogen. There is a need of adoption of integrated approach including gypsum and locally available organic materials for ameliorating sodicity. Bio-drainage should be preferred for minimizing the effect of salinity. Effective irrigation techniques preferably use of sprinklers and drips and *in situ* moisture conservation are extremely beneficial for biomass production and for keeping biomass cover on soils for longer duration

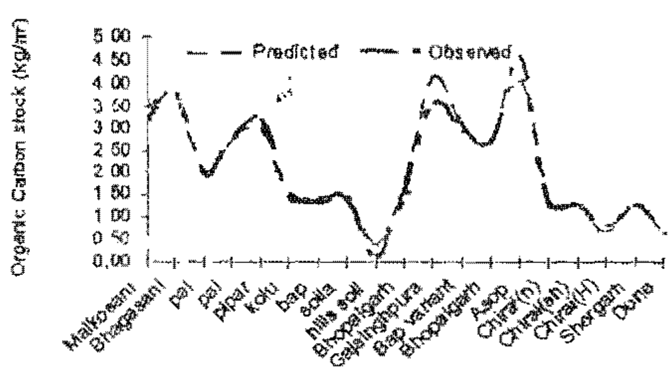

Fig. 8. Organic carbon stock in soils of Jodhpur Rajasthan

Soil erosion management is an important aspect of soil and water quality enhancement. The erosion involves removal of humus and clay fraction on which organic particle are adsorbed. Soil erosion control measures include engineering practices for runoff management and land management that decrease runoff by improving infiltration should be used adequately.

Good farming practices that improve agronomic productivity to enhance soil quality. These practices include improved crop varieties, cropping sequence and combination of nutrient management, appropriate seeding rate, weed control and integrated pest management and use of cover crops in the rotation cycle. Some of the striking strategies to maintain soil and water quality would be as under

- Strategies for improving soil and water quality of ecosystems contemplate issues of sustainable land management based on soil and water conservation and rational land use.
- Afforestation with energy crops, silvipasture, agro-forestry on non-arable land and good farming practices *viz.*, conservation tillage, cover crops, green manuring, crop rotations, intercropping, integrated nutrient and water management on arable land be adopted.
- A focus on rain water harvesting, its storage and efficient use with due consideration to recharging and utilization of ground water.
- These strategies are to be implemented on integrated farming system in consortia watershed mode through participatory approach of Government, NGO, Institutions and stakeholders.
- Policy interventions require to integrate Government launched program on enhancing dry land production, drought and flood relief *etc.* with land base activities for sustainable productivity, soil and water quality and survival of mankind for today and tomorrow

References

Aggrawal, R.K., Parveen-Kumar and Power, J.F. (1997) Use of crop residue and manure to conserve water and enhance nutrient availability and pearl millet yields in arid tropical region. *Soil Tillage Research* 41, 43-51.

Carter, M.R., Gregorich, E.G., Anderson, D.W., Doran, J.W., Janzen, H.H. and Pierce, F.J. (1997) Concept of soil quality and their significance. In *Soil Quality for Crop Production and Ecosystem Health* (E.G. Gregorich and M.R. Cater, eds.), Elsevier, Amsterdam, 448 p.

Carter, M.R., Andrew, S.S. and Drink Water (2004) Systems approaches for improving soil quality. In. *Managing Soil Quality: Challenges in Modern Agriculture* (P. Schjonning, S. Elmholt and B.T. Christensen, eds.), CAB International, 261-280.

CAZRI (1997) Impact Assessment of Industrial Effluents along the Jojari, the Bandi and the Luni rivers in Pali district of Rajasthan. Central Arid Zone Research Institute, Jodhpur.

CAZRI (2002) *Annual Report*, Central Arid Zone Reasearch Institute, Jodhpur, India.

CRIDA (2003-04) *Annual Reports NATP for Rainfed Agro-ecosystem*. Central Research Institute of Dryland Agriculture, Hyderabad, India.

Doran, J.W. and Parkin, T.B. (1996) *Quantitative Indicators of Soil Quality*. Soil Science Society of America Special Publication No.49 Madison, Wisconsin, pp 25-37

Doran, J.W., Sarrantanio, M. and Liebig, M.A. (1996) Soil health and sustainability. *Advances in Agronomy* 56, 1-54.

Doran, J.W. and Zeiss, M.R. (2000) Soil health and sustainability: managing the biotic component of soil quality *Applied Soil Ecology* 15, 3-11

Eswaran, H., Reich, P.F., Kimble, J.M., Beinroth, F.H., Padamnabhan, E. and Moncharoen, P. (1999) Global Climate Change and Pedogenic Carbonate. In: *Advances in Soil Science* (R. Lal, J.M. Kimble, H. Eswaran and B.A. Stewart, eds.) Lewis Publishers Boca Raton, FL, 15-25.

FAO/ UNEP (1984) *Map of Desertification Hazards*, UNEP, Nairobi, Kenya.

Franzmeir, D.P., Limme, G.D. and Miles, R.J. (1985) Organic Carbon in soils of north central United States. *Soil science Society of American Journal* 49, 702-708.

Gupta, S.K., Singh, N.T. and Sethi, M. (1994) *Ground Water Quality for Irrigation in India* (Map1; 6 Million Scale) Bulletin No. 19. Central Soil Salinity Reseacrh Institute, Karnal, India.

IPCC (2001) *Climate Change 2001*. The Scientific Basis, Special Report of the Inter-Governmental Panel on Climate. Change, Cambridge University Press, Cambridge

IISS (2002-03) *Annual Report*, Indian Institute of Soil Science, Bhopal, India.

IISS (2003-04) *Annual Report*, Indian Institute of Soil Science, Bhopal, India.

Katyal, J.C. (2003) Soil fertility management- A key to prevent desertification. *Journal of the Indian Society of Soil Science* 51,378-387.

Kumar, P., Aggrawal, R.K. and Power, J.F. (1997) Cropping System: Effects on soil quality indicators and yield of pearl millet in arid region *American Journal of Alternate Agriculture* 14, 178-184

Kumar, P., Joshi, N.L., Singh, D.V. and Saxena, Anurag (2004) Evaluation of pearl millet production systems for high yields and net carbon accumulation in soils and crop. *Journal of the Indian Society of Soil Science* 52, 95-99.

Lal, R. (1995) Global soils erosion by water and C dynamic. In: *Soil and Global Change* (R. Lal, J.M. Kimble, E. Levine and B.A. Stewart, eds.) CRC/ Lewis Publishers, Boca Raton, Florida, USA, pp 131-142.

Lal, R. (2004) Soil quality in industrialized and developing countries - Similarities and differences. In: *Managing Soil Quality. Challenges in Modern Agriculture* (P. Schjonning, S. Elmholt, and B.T. Christensen, eds.) CAB International, pp 297-313.

Lal, R. and Kimble, J.M. (2000) Conservation tillage; prospect for the future. *Proceedings of International Conference on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century*, New Delhi, India, pp 116-125.

Nambiar, K.K.M. (1995) Economic, Environmental and Statistical Considerations. In: *Agricultural Sustainability* (V. Barnett, R. Payne and R. Steiner, eds.) Wiley, UK, pp 130-170.

Narain, P. (2001) Strategies of carbon sequestration on degraded soils. *Journal of the Indian Society of Soil Science* 49, 634-644.

NBSS&LUP (1990) *Annual Report*, National Bureau of soil survey and Land Use Planning, Nagpur, India.

Rattan, R.K., Datta, S.P., Chandra, S. and Saharan, N. (2002) Heavy metals and environmental quality- Indian Scenario. *Fertilizer News* 47, 21-26 & 29-40.

Samra, J.S. and Pratap Narain (1998) Soil and water conservation. In: 50 *Years of Natural Resource Management Research* (G.B. Singh and B.R. Sharma, eds.) ICAR, New Delhi, pp 145-176.

Sarin, M.M., Krishnswami, K., Dilli, K., Somayajulu, B.L.K and Moore, W.S. (1989) Major ion chemistry of Ganga-Brahmputra river system: Weathering process and fluxes to Bay of Bengal. *Geochemica et Cosmochemica*, 53, 997-1009.

Schlesinger, W.H. (1982) Carbon storage in the calchic of soils a case study from Arizona. *Soil Science* 133, 247-255.

Sehgal, J.L. and Abrol, I.P. (1994) *Soil Degradation in India: Status and Impact*. Oxford and IBH Publishing Company, New Delhi.

Shyampura, R.L., Giri, J.D., Singh, S.K. and Das, K. (1994) Soil physiographic relationship in southern Rajasthan. *Journal of the Indian Society of Soil Science* 42, 623-625.

Singh, G. and Singh, N.T. (1993) In: *Mesquite for Vegetation of Salt Affected Soils* (Research Bulletin, No. 18). Central Soil Salinity Research Institute, Karnal, India.

Singh, S.K. and Pratap Narain (2005) A Soil quality assessment in arid ecosystem of Rajasthan - A case study in soils of Jodhpur. *Proceedings of the International Conference on Soil, Water and Environment Quality - Issues and strategies*, January 28 to February, 2005, New Delhi, 24.

Singh, S.K., Baser, B.L. and Shyampura, R.L. (2002) Chemical composition and charge behavior of smectites in Vertisols of Rajasthan. *Journal of the Indian Society of Soil Science* 50, 106-111.

Singh, Y.V., Parveen Kumar, Lodha, S. and Agrawal, R.K. (1998) *Consolidated Work Report ... Indo-US Project*. Central Arid Zone Research Institute, Jodhpur, India.

Solanki, K.R., Bisaria, A.K. and Handa, A.K. (1999) In *Sustainable Rehabilitation of Degraded Land through Agri Forestry*. National Research Center for Agro-forestry, Jhansi, India.

Velayutham, M., Pal, D.K. and Bhattacharyya, T. (2000). Organic carbon stock in soils of India. In: *Advances in Soil Sciences* (R. Lal, J.M. Kimble and B.A. Stewart, eds.) CRC/ Lewis Publishers, Boca Raton, Florida, USA, pp 71-95.

Yadav, J.S.P. (2003) Managing soil health for sustained high productivity. *Journal of the Indian Society of Soil Science*, 51, 448-465.

Wani, S.P., Baloli, S.S., Kesava Rao, A.V.R., Sreedevi, T.K. (2004) Combating drought through integrated watershed management for sustainable dry land agriculture. *Proceedings of the UNESCAP/NRSA Regional Workshop on Agricultural Drought Monitoring and Assessment, Using Space Technology*, May 3-7, Hyderabad, India.